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FEATURES OF THE SOLAR ARRAY DRIVE MECHANISM
FOR THE SPACE TELESCOPE

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ABSTRACT

The Solar Array Drive Mechanism for the Space Telescope embodies several features not customarily found on Solar Array Drives. Power and signal transfer is achieved by means of a flexible wire harness for which the chosen solution, consisting of 168 standard wires, is described. The torque performance data of the harness over its temperature range are presented. The off-load system which protects the bearings from the launch loads is released by a trigger made from Nitinol, the memory alloy. The benefits of memory alloy and the caveats for the design are briefly discussed. The design of the off-load system is described and test experience is reported.

INTRODUCTION

The solar array is part of the equipment contributed to NASA's Space Telescope (ST) by the European Space Agency. Figure 10 shows an overall view of the ST Solar Array (SA). The Solar Array Drive Mechanism (SADM) and its electronics are a subassembly of the SA. The rotational range of the wings is limited to some 340 degrees because of vehicle pointing constraints which prevent the sunlight from getting into the ST aperture. Under these circumstances a flexible wire harness is an obvious choice for the transfer of a large number of electrical channels.

In the launch configuration the SAs are stowed along the ST body and fixed by clamps. Since the loads induced into the SADM through the primary deployment mechanism exceed the load-carrying capability of the bearings, it was necessary to provide an off-load system in order to protect them. Because pyrotechnic devices were banned from use in the SADM, memory alloy elements were chosen to trigger the release of the bearing off-load device.

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FLEXIBLE WIRE HARNESS

Each SA wing provides 10 solar cell modules with a nominal current of 7.5 A each. These modules were wired independently from each other and the wiring had to be redundant. This resulted in a minimum of 40 lines of AWG 16 for 50 percent derating.

In addition to these SA power lines, 20 wires with a maximum capacity of 3 A were required for the redundant motors of the primary and secondary deployment mechanisms, the redundant resolvers of the solar array drive itself and for bonding.

Finally, 68 housekeeping data lines were needed with a current capacity of up to 250 mA. These data lines had to be separated from the power lines by a screen.

Since a high wind-up torque was anticipated from the American Wire Gauge (AWG) 16 wires needed for the SA power, it was necessary to find an alternative which met the redundancy approach which aimed to avoid single point failures for vital functions. The chosen approach utilized 80 cables AWG 22, of which 20 cables are for redundancy purposes.

Four options of flexible wire harnesses were studied by breadboarding and analysis. The trade-off is presented in Table 1.

Though torque, torque noise and hysteresis of the flexible wire harness played an important role in the design of the SADM control system, the printed circuit, which is best in these respects, was not selected. The printed conductors for power transfer would have had to be very wide in order to achieve the necessary cross section. In addition to serious difficulties at the Printed Circuit (PC)/connector interface, this design would have exceeded the given envelope, even with a double-layer arrangement of the PC belts and a reduced derating. In fact the criterion of compatibility with the given volume rendered the option with the single wires the only feasible solution.

The principle of the chosen solution is shown in Figure 1. The axial degree of freedom required for one cable end of this twisted wire configuration was provided by performing the cables in a half circle from their shaft location towards their fixation points at the stator. Twisting and shielding of cable pairs within the flexible wire harness was discarded because it impaired cable flexibility. The required shielding between the signal lines and the power lines is achieved by a screening tube. The signal lines (68 off AWG 24) pass through the screening tube and the power lines (100 off AWG 22) are arranged in the annulus between the tube and the hollow shaft. The length of the flexible wires amounts to some 580 mm. Although the wires are neither fixed nor tied together over that length, both a centrifuge test, giving up to 4.5 g's, and vibration tests showed that the wires would suffer no permanent deformation as a result of the launch mechanical environment.

The torque at the boundaries of the rotational range is adjusted to about the same level by suitable pre-orientation of the power and signal leads during assembly. A breadboard model (see Fig. 5) was built in order to determine the spring constant, torque noise and hysteresis characteristics of the harness. The wires were short-circuited outside the flexlead compartment. This allowed the routing of current through the leads and the determination of their performance at elevated temperatures. Low-temperature tests down to -25°C were carried out in a large temperature chamber. The results met expectations and, with a margin of 2, were taken into account for the design of the control circuit.

Following testing of the Qualification Model SADM in a dynamic test rig, to verify pointing accuracy and interactive torque between the ST and the wings, it was demonstrated that the torque characteristics of the flexible wire harness had an unexpectedly large impact on the system performance. Both maximum torque and hysteresis of the flight-configured qualification model exceeded the corresponding values of the breadboard model by a factor of 3, even though the flexleads inside were identical. The difference was attributed to the harness located outside the flexlead section. In contrast to the short-circuit looms of the breadboard model, the cables of the Qualification Model harness outside the mechanism were twisted, shielded, bundled and fixed as required to form the conventional harness between the SA panel and the diode box (see Fig. 6). These measures had resulted in a deterioration of the torque and hysteresis characteristics to an unexpected extent. By corrective actions, e.g., deletion of most of the spare lines and provision of slight slack at those tie-down points where the bundles emerge from the housing, it was possible to recover the original harness performance.

The harness torque and hysteresis characteristics of the flight model mechanisms are summarized in Figures 2, 3 and 4.

Figure 2 shows the basic shape of the torque/hysteresis loop for the full angular range. Torque rises linearly as the shaft is rotated in one direction. Upon reversal there is a steep (1°) decay of torque followed by a steady transition (10°) towards the linear wind-back behavior. The area between wind-up and wind-back torque is due to hysteresis. As a result of the deletion of spare lines, which were mainly in the signal section, the hysteresis is not constant over the whole angular range. The mechanical properties of the wire insulation are changed by temperature fluctuations of the harness. This affects the whole torque envelope, i.e., the slopes and resulting maximum torques as well as the hysteresis.

Figures 3 and 4 show the maximum torque values at the ends of the angular range and the corresponding hystereses as functions of temperature. The data for a specific temperature give the corners of the torque envelope "trapezoid".

OFF-LOAD SYSTEM

Discussion of Memory Alloy

Nitinol Memory Alloy Elements (MAE) are used as release triggers for the off-load system. The choice of this actuator type was encouraged by some experience from a joint test programmer with the manufacturer and from in-house development studies.

The memory effect is based on a reversible martensitic transformation of the crystal lattice of the nickel-titanium alloy. The effect is imparted by plastic deformation of the element at low (ambient) temperature. When subsequently heated above the transformation temperature, the element returns almost completely to its initial shape. All kinds of motion can be achieved: bending or torsion, expansion or contraction. During motion, the element is capable of exerting a force (or torque). Both force and stroke are controlled by the dimensions of the element. The trigger temperature can be adjusted by the manufacturer rather accurately by controlling the percentage of the alloy constituents. If an "educating force" is applied during cooling, the effect can repeat many times.

These characteristics suggest a very simple design for all kinds of mechanisms which have to lock or release an item. However there are some constraints which limit the use of memory alloy:

- machining is very difficult because the alloy is susceptible to heat, developed by most machining processes, and to work-hardening. Therefore the shape of the element should be simple, commensurate with the still-growing experience of the manufacturer.
- together with the desired stroke there is a minute change of the other dimensions of the element resulting from the alteration of the crystal structure.
- when the element cools, after having produced the memory effect, it may, to a certain extent, return to its deflected shape.
- the efficiency of mechanical energy output to heating energy input is very low compared to other systems.

If these constraints are taken into account with the design, memory alloy can be a suitable material for relatively cheap actuator elements.

Description of the System

The SADM is equipped with two separable, thin-section, angular-contact ball bearings in a back-to-back mounting. The outer race of one bearing is fixed to the housing through a diaphragm which controls the axial preload. This arrangement allows a slight axial displacement of the shaft, with the result that the bearing in the diaphragm experiences small increased axial load

corresponding to the additional deflection of the diaphragm, and the other bearing becomes completely unloaded.

This method is utilized by the off-load device of the SADM. Figure 7 shows two orthogonal views of the off-load device.

Four supports are mounted on the outboard front face of the mechanism housing, and extend two tabs each over a collar at shaft. "L"-shaped rocking levers are hinged in the supports (see Fig. 7). Under a radial force the levers press against the collar from underneath, lifting the shaft and clamping it against the tabs of the supports. The radial force is applied to the rocking levers by a cable through intermediate levers which are hinged between the side walls of the rocking levers. The cable is routed over pulley segments mounted on the intermediate levers. Rotation of the intermediate levers is prevented by locking elements. In two places the locking elements are bolts, and in the other two places there are latches. The latch position is secured by a pin made of Nitinol protruding through an eye in the latch. The pin is fixed by a bracket which is bolted to the housing. The shaft is released as one of the locking elements (bolt or latch) is disengaged from the corresponding intermediate lever.

Automatic release is performed by one of the MAEs. The MAEs are mounted to the mechanism in a bent form. A tubular heater encloses each element. When heated up to the threshold temperature the element becomes straight and lifts the latch. Under the pre-tension of the cable, the intermediate lever rotates outwards. The cable is then disengaged from the pulleys and secured by four soft springs on a sheet metal tray which is located underneath the off-load system (see Fig. 8). Since only one locking element has been removed, the other intermediate levers move inwards together with their main rocking levers under the action of springs. The shaft is then pulled back into its operational position by the diaphragm.

In an emergency, when the off-load device cannot be released, even by one of the redundant MAEs, an astronaut can unlock one of the other intermediate levers by actuating one of the bolts. This bolt is accessible through a hole in the thermal shield. Release is verified by redundant micro-switch circuits.

This rather complex configuration evolved from a series of breadboard tests. Initially the MAE was clamped in a slot between the main rocking lever and the intermediate lever (see Fig. 9). When heated to the trigger temperature, the MAE deformed into a flat "S"-shape rather than becoming straight, because friction could not be controlled effectively. The problem was solved by the introduction of the latch. The force required to lift the latch is less than 50 percent of the capability of the MAE. However it was necessary to add a spring to prevent the intermediate lever from swinging back to its original position since, during cooling down after release, the MAE could deform back and reengage the latch, thereby jamming the shaft again.

The MAEs for the SADM off-load system have a diameter of 10 mm, a length of 56 mm and a force capability of more than 450 N over the full stroke of 6 mm. The trigger temperature amounts to 115°C which is well above the hot survival temperature of 85°C stipulated for the SADM. After use, MAEs can be "recharged" by the manufacturer (which involves a heat-treatment) to achieve the same certified performance.

For development tests, however, it is sufficient to rebend the MAE at ambient temperature to restore the memory. More than 10 consecutive reuse cycles have been achieved, this being a notable economic advantage over the use of pyrotechnics. Only a gradual decrease of the trigger temperature has been observed in this series.

The heaters consist of a heating wire embedded in silicone rubber. At the nominal power output of 40 Watts, the trigger temperature is reached after about 100 seconds when starting from ambient conditions and about 180 seconds when starting from -60°C thermal vacuum conditions.

Thirty-five of the procured lot of 60 MAEs have been subjected to date to formal qualification and acceptance tests. The first 25 elements were used for lot qualification. This qualification included verification of the dimensions prior and after subjection to hot and cold survival temperatures and subsequent function tests in order to demonstrate strength and stroke capability at the trigger temperature. The other 10 elements were used to release the off-load devices of the individual SADM models during the course of the program. The tests demonstrated the Nitinol elements can be a reliable replacement for pyrotechnics.

CONCLUSIONS

Based on the experience with the SADM harness, similar flexible wire harnesses have been implemented in further space mechanisms, e.g., the gimbal drives of the Instrument Pointing System (IPS) for the Spacelab.

The utilization of memory alloy elements for other space applications has not yet progressed beyond breadboarding. At the present time the prime impetus in MAE development comes from terrestrial applications ranging from Nitinol motors to medical applications, and there is considerable progress being made in the manufacturing techniques applied to these useful alloys.

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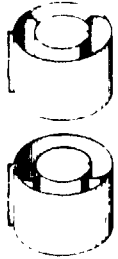

| Flexible Wire Harness Type |  |  |  |  |
|-------------------------------------|---|---|---|---|
| Cable Design | Standard Belts | Standard Belts | PC (Special Design) | Standard Wires |
| Qty. of Power Segments Signal | 2 2 | 1 1 | 1 1 | 1 1 |
| Cable Arrangement in Segments | Multi-Layer | Multi-Layer | Double Layer | Per Rate Wires |
| Connector | Conventional | Conventional | Special Design | Conventional |
| Shielding Between Power & Signal | Easy | Difficult | Easy | Easy |
| Rel. Cable Length | 1.5 | 1 | 0.3 - 0.4 | 1 |
| Rel. Power Dissipat. | 1.5 | 1 | 1.8 - 2.0 | 1 |
| Heat Radiation | Poor | Poor | Poor | Fair |
| Torque & Torque Characteristic | Low; Constant | Low; Torsing | Very Low; Const. | Low; Torsing |
| Torque Noise | High (Multi-Layer) | High (Multi-Layer) | Very Low | Fair |
| Hysteresis | Large | Large | Very Small | Large |
| Growth Flexibility | Margin by Design | Moderate | Poor | Good |
| Assembly | Fair | Difficult | Easy | Easy |
| Compatibil. with Given Volume | No | No | No | Yes |

Table 1 Flexible Wire Harness Trade-off

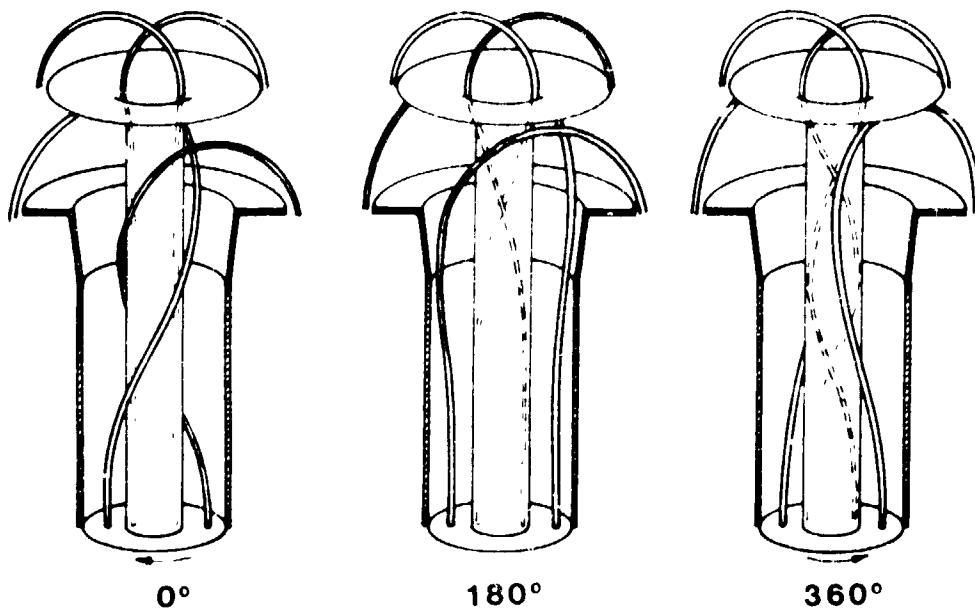


Fig. 1 Flexible Wire Harness - Schematic

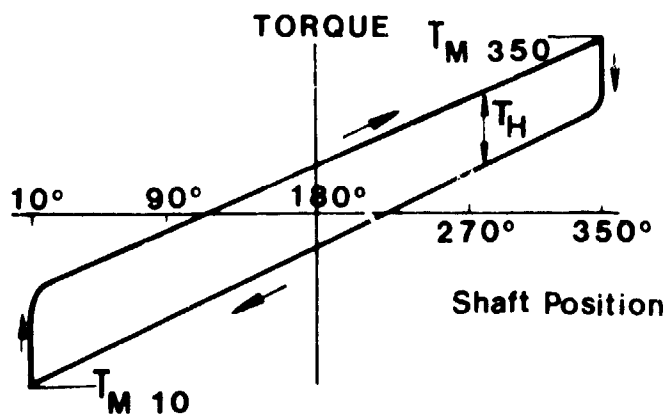


Fig. 2 Flexible Wire Harness Torque Envelope as Function of Shaft Position

MAXIMUM HARNESS TORQUES AND HYSTERESES **(AT THE BOUNDARIES OF SAD ROTATIONAL RANGE)** **AS FUNCTIONS OF TEMPERATURE**

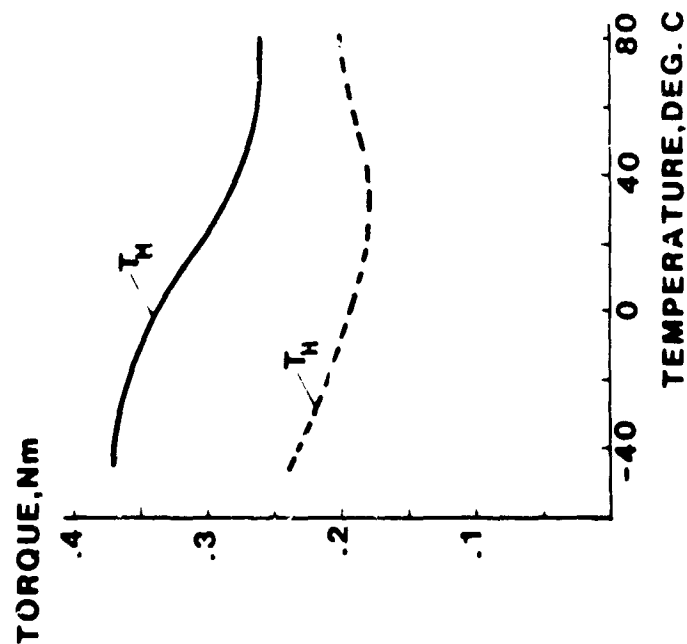


Fig. 3 Maximum Torque T_M and Hysteresis T_H at Position 10°

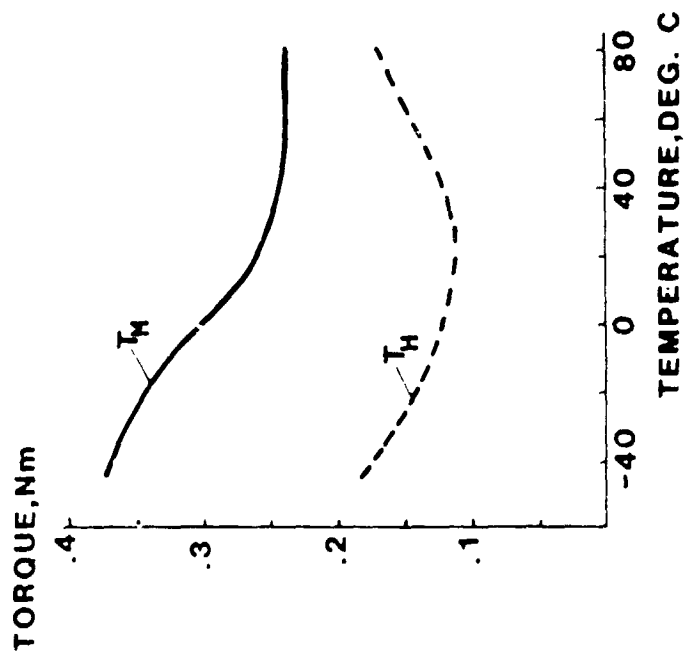


Fig. 4 Maximum Torque T_M and Hysteresis T_H at Position 350°

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Fig. 5 Flexible Wire Harness
Breadboard Model

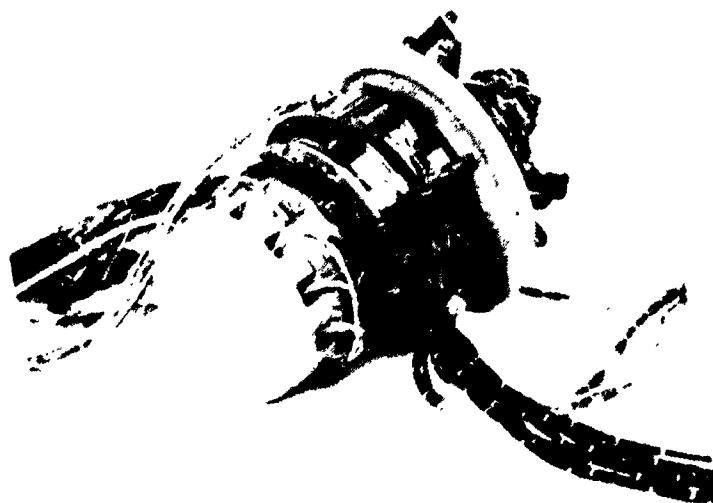
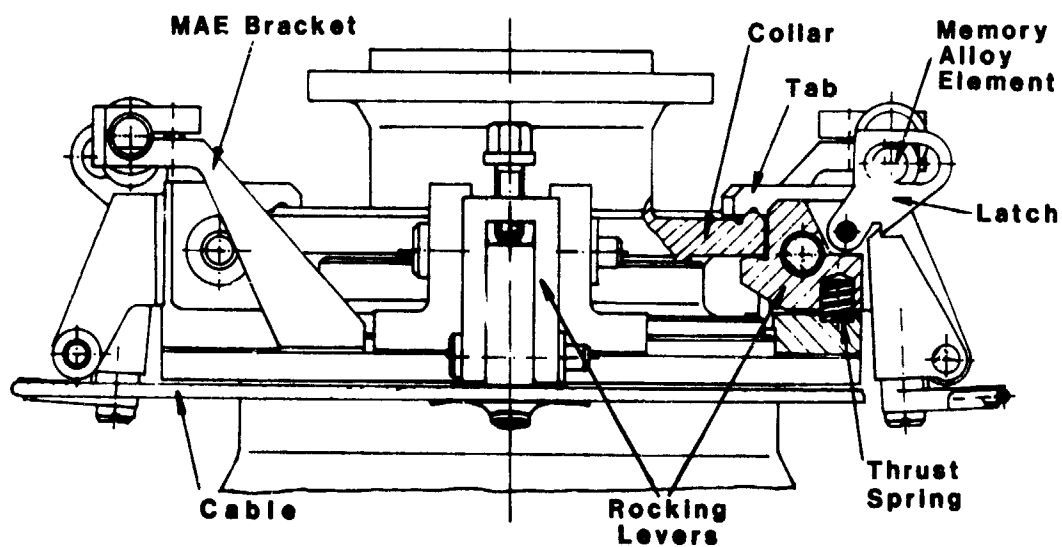
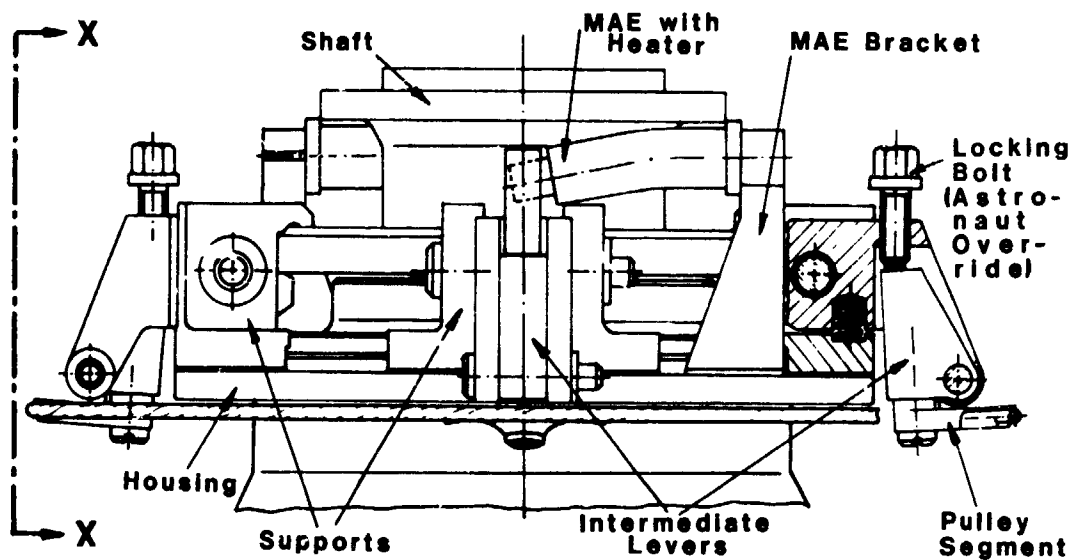


Fig. 6 Harness Configuration
Qualification Model

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Fig. 7 Off-Load Device

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Fig. 8 Off-Load Device
Qualification Model



Fig. 9 Off-Load Device
Breadboard Model

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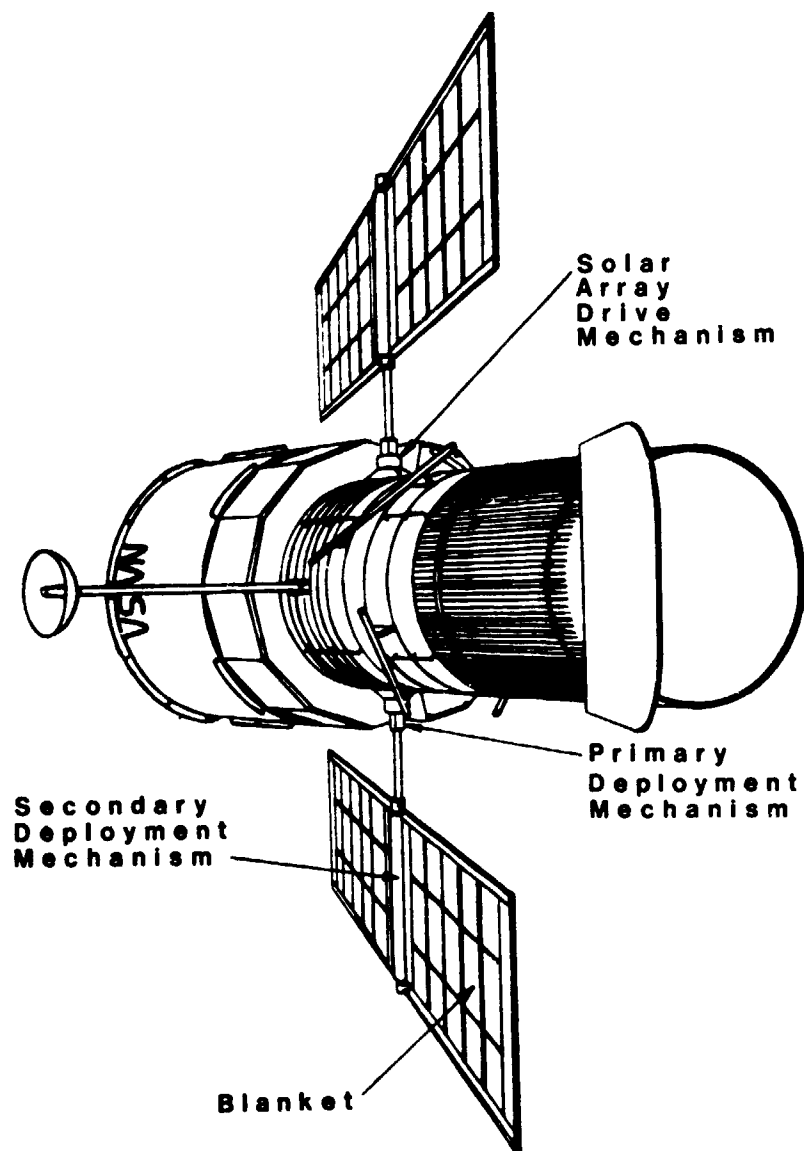


Fig. 10 ST - SA Orientation &
Deployment Mechanisms